Journal of Nanomaterials 2017 vol.2017

Physical Background for Luminescence Thermometry Sensors Based on Pr^{3+}:LaF3 Crystalline Particles

Pudovkin M., Morozov O., Pavlov V., Korableva S., Lukinova E., Osin Y., Evtugyn V., Safiullin R., Semashko V.

Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2017 Maksim S. Pudovkin et al. The main goal of this study was creating multifunctional nanoparticles based on rare-earth doped LaF 3 nanocrystals, which can be used as fluorescence thermal sensors operating over the 80-320 K temperature range including physiological temperature range (10-50°C). The Pr 3+ :LaF 3 (CPr = 1%) microcrystalline powder and the Pr 3+ :LaF 3 (CPr = 12%, 20%) nanoparticles were studied. It was proved that all the samples were capable of thermal sensing into the temperature range from 80 to 320 K. It was revealed that the mechanisms of temperature sensitivity for the microcrystalline powder and the nanoparticles are different. In the powder, the 3 P 1 and 3 P 0 states of Pr 3+ ion share their electronic populations according to the Boltzmann and thermalization of the 3 P 1 state takes place. In the nanoparticles, two temperature dependent mechanisms were suggested: energy migration within 3 P 0 state in the temperature range from 80 K to 200 K followed by quenching of 3 P 0 state by OH groups at higher temperatures. The values of the relative sensitivities for the Pr 3+ :LaF 3 (CPr = 1%) microcrystalline powder and the Pr 3+ :LaF 3 (CPr = 12%, 20%) nanoparticles into the physiological temperature range (at 45°C) were 1, 0.5, and 0.3% °C -1 , respectively.

http://dx.doi.org/10.1155/2017/3108586

References

[1] D. Jaque and F. Vetrone, "Luminescence nanothermometry, " Nanoscale, vol. 4, no. 15, pp. 4301-4326, 2012.

[2] G. P. Szakmany, A. O. Orlov, G. H. Bernstein, and W. Porod, "Single-metal nanoscale thermocouples, " IEEE Transactions on Nanotechnology, vol. 13, no. 6, pp. 1234-1239, 2014.

[3] J. P. Kauppinen and J. P. Pekola, "Coulomb blockade nanothermometer, " Microelectronic Engineering, vol. 41-42, pp. 503-506, 1998.

[4] C. D. S. Brites, P. P. Lima, N. J. O. Silva et al., "Thermometry at the nanoscale, " Nanoscale, vol. 4, no. 16, pp. 4799-4829, 2012.

[5] X.-D. Wang, O. S. Wolfbeis, and R. J. Meier, "Luminescent probes and sensors for temperature, " Chemical Society Reviews, vol. 42, no. 19, pp. 7834-7869, 2013.

[6] Y. Y. Bu, S. J. Cheng, X. F. Wang, and X. H. Yan, "Optical thermometry based on luminescence behavior of Dy3+-doped transparent LaF3 glass ceramics, " Applied Physics A, vol. 121, no. 3, pp. 1171-1178, 2015.

[7] G. Tessier, M. Bardoux, C. Bo, C. Filloy, and D. Fournier, "Back side thermal imaging of integrated circuits at high spatial resolution, " Applied Physics Letters, vol. 90, no. 17, 2007.

[8] B. Dong, B. Cao, Y. He, Z. Liu, Z. Li, and Z. Feng, "Temperature sensing and in vivo imaging by molybdenum sensitized visible upconversion luminescence of rare-earth oxides, " Advanced Materials, vol. 24, no. 15, pp. 1987-1993, 2012.

[9] E. C. Ximendes, U. Rocha, K. U. Kumar, C. Jacinto, and D. Jaque, "LaF3 core/shell nanoparticles for subcutaneous heating and thermal sensing in the second biological-window, " Applied Physics Letters, vol. 108, no. 25, 2016.

[10] U. Rocha, C. Jacinto Da Silva, W. Ferreira Silva et al., "Subtissue thermal sensing based on neodymium-doped LaF3 nanoparticles, " ACS Nano, vol. 7, no. 2, pp. 1188-1199, 2013.

[11] E. C. Ximendes, W. Q. Santos, U. Rocha et al., "Unveiling in vivo subcutaneous thermal dynamics by infrared luminescent nanothermometers, " Nano Letters, vol. 16, no. 3, pp. 1695-1703, 2016.

[12] Y. Gao, F. Huang, H. Lin, J. Xu, and Y. Wang, "Intervalence charge transfer state interfered Pr3+ luminescence: A novel strategy for high sensitive optical thermometry, " Sensors and Actuators, B: Chemical, vol. 243, pp. 137-143, 2017.

[13] X. Rao, T. Song, J. Gao et al., "A highly sensitive mixed lanthanide metal-organic framework self-calibrated luminescent thermometer, " Journal of the American Chemical Society, vol. 135, no. 41, pp. 15559-15564, 2013.

[14] H. Dong, S.-R. Du, X.-Y. Zheng et al., "Lanthanide nanoparticles: from design toward bioimaging and therapy, " Chemical Reviews, vol. 115, no. 19, pp. 10725-10815, 2015.

[15] A. B. Shcherbakov, N. M. Zholobak, A. E. Baranchikov, A. V. Ryabova, and V. K. Ivanov, "Cerium fluoride nanoparticles protect cells against oxidative stress, " Materials Science and Engineering C, vol. 50, pp. 151-159, 2015.

[16] M. L. Debasu, D. Ananias, I. Pastoriza-Santos, L. M. Liz-Marzn, J. Rocha, and L. D. Carlos, "All-in-one optical heaterthermometer nanoplatform operative from 300 to 2000 K based on Er3+ emission and blackbody radiation, " Advanced Materials, vol. 25, no. 35, pp. 4868-4874, 2013.

[17] M. D. Dramianin, Z. Anti, Sulubrk, S. P. Ahrenkiel, and J. M. Nedeljkovi, "Self-referenced luminescence thermometry with Sm3+ doped TiO2 nanoparticles, " Nanotechnology, vol. 25, no. 48, 2014.

[18] U. Rocha, K. U. Kumar, C. Jacinto et al., "Nd3+ doped LaF3 nanoparticles as self-monitored photo-Thermal agents, " Applied Physics Letters, vol. 104, no. 5, 2014.

[19] V. K. Rai, D. K. Rai, and S. B. Rai, "Pr 3+ doped lithium tellurite glass as a temperature sensor, " Sensors and Actuators, A: Physical, vol. 128, no. 1, pp. 14-17, 2006.

[20] M. Kaczkan, Z. Boruc, B. Fetlinski, S. Turczynski, and M. Malinowski, "Temperature dependence of 3P0 Pr3+ fluorescence dynamics in Y4Al2O9 crystals, " Applied Physics B: Lasers and Optics, vol. 113, no. 2, pp. 277-283, 2013.

[21] I. Kamma, P. Kommidi, and B. R. Reddy, "High temperature measurement using luminescence of Pr3+ dopedYAGandHo3+ doped CaF2, " Physica Status Solidi (C) Current Topics in Solid State Physics, vol. 6, no. 1, pp. S187-S190, 2009.

[22] Y. An, A. Duhaime, and P. S. May, "Optical observation of the kinetics of thermalization between the 3P0 and 3P1 excited states of Pr3+ in symmetrical Pr3+-Gd3+ pairs in CsCdBr3, " Journal of Luminescence, vol. 111, no. 3, pp. 131-138, 2005.

[23] E. Cavalli, P. Boutinaud, and M. Grinberg, "Luminescence dynamics in CaWO4:Pr3+ powders and single crystals, " Journal of Luminescence, vol. 169, pp. 450-453, 2016.

[24] M. S. Pudovkin, P. V. Zelenikhin, A. O. Krasheninnikova et al., "Photoinduced toxicity of PrF3 and LaF3 nanoparticles, " Optics and Spectroscopy, vol. 121, no. 4, pp. 538-543, 2016.

[25] E. M. Alakshin, A. V. Klochkov, E. I. Kondratyeva et al., "Microwave-Assisted hydrothermal synthesis and annealing of DyF3 nanoparticles, " Journal ofNanomaterials, vol. 2016, Article ID 7148307, 5 pages, 2016.

[26] E. M. Alakshin, R. R. Gazizulin, A. V. Klochkov et al., "Annealing of PrF3 nanoparticles by microwave irradiation, " Optics and Spectroscopy, vol. 116, no. 5, pp. 721-723, 2014.

[27] O. A. Morozov, A. K. Naumov, A. V. Lovchev, and E. Y. Tselishcheva, "Up-conversion luminescence of LaF3:Pr3+ crystal, " Journal of Physics: Conference Series, vol. 560, no. 1, article 012012, 2014.

[28] S. P. Feofilov, "Spectroscopy of dielectric nanocrystals doped by rare-earth and transition-metal ions, " Physics of the Solid State, vol. 44, no. 8, pp. 1407-1414, 2002.

[29] H. Okamoto, K. Kasuga, I. Hara, and Y. Kubota, "Visible-NIR tunable Pr3+-doped fiber laser pumped by a GaN laser diode, " Optics Express, vol. 17, no. 22, pp. 20227-20232, 2009.

[30] J. W. Stouwdam, G. A. Hebbink, J. Huskens, and F. C. J. M. van Veggel, "Lanthanide-doped nanoparticles with excellent luminescent properties in organic media, " Chemistry of Materials, vol. 15, no. 24, pp. 4604-4616, 2003.

[31] P. Boutinaud, R. Mahiou, N. Martin, and M. Malinowski, "Luminescence from Pr3+3P1 and 3P2 states in -NaYF4: Pr3+, " Journal of Luminescence, vol. 72-74, pp. 809-811, 1997.

[32] G. F. Imbusch and B. Henderson, Optical Spectroscopy of Inorganic Solids, Oxford Science Publications, London, UK, 2006.

[33] C.-H. Huang, L. Luo, Y.-T. Yeh, S.-M. Jang, and W.-R. Liu, "Novel red-emitting garnet Na2CaTi2Ge 3O12:Pr3+, Na+ phosphors, " RSC Advances, vol. 4, no. 11, pp. 5513-5517, 2014.

[34] H. Suo, C. Guo, and T. Li, "Broad-scope thermometry based on dual-color modulation up-conversion phosphor Ba5Gd8Zn4O21:Er3+/Yb3+, " Journal of Physical Chemistry C, vol. 120, no. 5, pp. 2914-2924, 2016.

[35] H.-S. Yang, K. S. Hong, S. P. Feofilov, B. M. Tissue, R. S. Meltzer, and W. M. Dennis, "Electron-phonon interaction in rare earth doped nanocrystals, " Journal of Luminescence, vol. 83-84, pp. 139-145, 1999.

[36] P. M. Selzer, D. S. Hamilton, R. Flach, and W. M. Yen, "Phonon-Assisted energy migration in Pr3+ : LaF3, " Journal of Luminescence, vol. 12-13, no. C, pp. 737-741, 1976.

[37] E. M. Alakshin, D. S. Blokhin, A. M. Sabitova et al., "Experimental proof of the existence of water clusters in fullerene-like PrF3 nanoparticles, " JETP Letters, vol. 96, no. 3, pp. 181-183, 2012.

[38] K. Ramasesha, L. De Marco, A. Mandal, and A. Tokmakoff, "Water vibrations have strongly mixed intra-And intermolecular character, "Nature Chemistry, vol. 5, no. 11, pp. 935-940, 2013.

[39] J. K. Krebs, S. P. Feofilov, A. A. Kaplyanskii, R. I. Zakharchenya, and U. Happek, "Non-radiative relaxation of Yb3+ in highly porous-Al2O3, " Journal of Luminescence, vol. 83-84, pp. 209-213, 1999.

[40] M. Ren, C. D. S. Brites, S.-S. Bao, R. A. S. Ferreira, L.-M. Zheng, and L. D. Carlos, "A cryogenic luminescent ratiometric thermometer based on a lanthanide phosphonate dimer, " Journal of Materials Chemistry C, vol. 3, no. 33, pp. 8480-8484, 2015.

[41] C. D. S. Brites, A. Milln, and L. D. Carlos, "Lanthanides in luminescent thermometry, " in Handbook on the Physics and Chemistry of Rare Earths, vol. 49, pp. 339-427, 2016.